Reconstructing Causal Reasoning about Evidence: a Case Study

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Abstract. When procedural-support systems are to be useful in practice, they should provide support for causal reasoning about evidence. Such support should be both rationally well-founded and natural to the users of such systems. This article studies two possible foundations for such support, logics for defeasible argumentation and logical models of causal-abductive reasoning. A court decision about a car accident is reconstructed in the two formalisms, and the results are compared on both their rationality and their naturalness. It is concluded that more research is needed to combine the strong points of the two approaches.

1 Introduction

This article addresses the reconstruction of causal reasoning about evidence in procedural-support systems. Procedural-support systems are AI & Law programs that lack domain knowledge and thus cannot solve problems, but that instead help the participants in a dispute to structure their reasoning and discussion, thereby promoting orderly and effective disputes. For instance, they support humans in building arguments for and against their claims, such as the ArguMed system of Verheij [16]. Or they keep track of what has been claimed, conceded and disputed and which arguments for and against claims have been provided, such as the Pleadings Game [2] and ZENO [4] systems. Sometimes they also check whether the parties' input to the system respects the disputational protocol, such as the Pleadings Game and DiaLaw [7]. After a decade of theoretical research on such systems (see also e.g. Loui et al. [8], Lodder [7], Bench-Capon et al. [1], Hage [5], Prakken [11]) their practical application becomes within reach, for instance, in online dispute resolution [6] and in case management; cf. e.g. the CaseMap system (www.casesoft.com).

Although much theoretical insight has been gained, one issue has so far largely been ignored, namely, the support of reasoning about evidence, especially about causation (with the

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exception of the MarshalPlan system of Schum and Tillers [14]). Yet this kind of reasoning is an important element of many legal cases, so procedural-support systems should ideally facilitate its reconstruction. The question then arises which reasoning formalisms provide suitable foundations for such support.

In this paper we investigate the suitability of two candidates, logics for defeasible argumentation and logical models of abductive-causal reasoning (see Prakken and Vreeswijk [13] and Lucas [9] for overviews of these two areas). We do so by reconstructing the reasoning in a Dutch court decision about a car accident with the two formalisms, and comparing the results. To the best of our knowledge, this is the first time that a formal model of abductive-causal reasoning is applied to legal reasoning.

An important requirement for procedural-support systems is that they should employ concepts that are natural to the intended users; see e.g. Gordon and Karaçapilidis [3], Prakken [12]. For instance, users should not be forced to use complicated formal syntax, and the system should structure the users' reasoning in terms that are natural and familiar to them rather than with difficult mathematical or logical computations. Accordingly, the problem statement of this paper can be rephrased as follows: to which extent can the reasoning in the studied case be reconstructed in the two formalisms in a way that is both rationally acceptable and reasonably close to the actual text of the decision?

The two formalisms have been chosen since there are grounds to believe that they have the potential to support such reconstructions. Argumentation systems model reasoning in terms of intuitive concepts, such as argument, counterargument, attack, defeat and dispute; moreover, arguments need not be complex logical derivations but can also be, for instance, linked or tagged pieces of natural language. Models of abduction can be based on simple and natural causal models, which, moreover, can easily be depicted in a graphical way.

The rest of this paper is structured as follows. In Section 2 the case to be reconstructed is presented, after which in Section 3 the two formalisms will be presented. Then in Section 4 an abductive-logical reconstruction and in Section 5 an argument-based reconstruction of the case is given. The results are compared and discussed in Section 6.

2 The Case

The case to be reconstructed concerns a one-car accident which took place while the driver and a passenger were returning late at night from a birthday party. The passenger sued the driver for the damages he suffered, claiming that driver had caused the accident by losing control over the car while there was no sign of another car or obstacle. Driver argued in defence that not she but plaintiff had caused the accident, by suddenly pulling the handbrake. We reconstruct the case as it took place in the court of appeal, as reported in the Dutch Supreme-Court decision HR 23 October 1992, NJ 1992, 813. The case is a civil case, which means that the judge must decide it on the basis of the facts adduced by the parties, and that s/he must accept undisputed factual claims. If a factual claim is disputed, the judge allocates the burden of proof and, after evidence is provided, decides whether this evidence indeed proves the claim to-be-proven.

The report of the police officers who arrived at the scene just after the accident makes the following undisputed observations. The accident occured beyond an S-curve. Tire marks caused by locked tires (skidmarks) were found just beyond the curve, and tire marks caused by a sliding vehicle (yaw marks) were found 25 meters further down the road. The police officers heard the driver saying three times that passenger had pulled the handbrake, and they observed that the handbrake was in pulled position. A second, technical police report, also undisputed, adds to this that at or near the accident site there was no sign of any obstacles or other unusual circumstances. Both police reports give a detailed analysis of the tire marks. There also is an undisputed expert witness report, stating that with the type of car that accidented, pulling the handbrake while driving can cause the wheels to lock. A final undisputed fact (of which the text of the decision reveals no source) is that the passenger had drunk alcohol.

Now, following the text of the decision as closely as possible, the court's decision can be summarised as follows. The court starts with a summary of plaintiff's and defendant's main arguments (first paragraph), then assesses a secondary argument of plaintiff (second paragraph), and finally (in the remaining paragraphs) assesses plaintiff's main argument. (Our summary leaves implicit the reasoning step from 'The report says that P' to P. This simplification is warranted since the police and expert reports were undisputed.)

> Plaintiff says that driver lost control over vehicle, thereby causing the accident. Defendant says that passenger pulled the handbrake beyond the S-curve, which caused the wheels to lock, which in turn caused skidding, leading to the accident.
>
> Given the nature and location of the skidmarks (starting after the curve and straight for 12 meters) and yaw marks (located 25m beyond the curve), the evidence insufficiently supports plaintiff's suggestion that driver had been speeding in the S-curve. Rather, this evidence suggests that driver had slowed down in the S-curve.
>
> The court regards another cause for the accident not unlikely, given:
>
> - driver's testimony that "passenger pulled the handbrake".
> - the handbrake was in pulled position after the accident.
> - the expert testimony that pulling the handbrake can cause the wheels to lock.
> - the location, nature and shape of the tire marks.
>
> In addition, the court attaches some value to:
>
> - the fact that driver and passenger were returning from a birthday party late in the night;
> - the fact that passenger had drunk, so that it is not inconceivable that he interfered with the driving.
>
> In this case, the sole fact that the car crashed is insufficient to conclude that defendant is responsible for causing the accident, since alternative causes cannot be sufficiently excluded.

$$\frac{C \Rightarrow E \quad E}{C}$$

Figure 1: The basic scheme of abduction

The reader will observe that this text does not allow a straightforward logical reconstruction. For instance, in the second paragraph the court evaluates a secondary argument of plaintiff, which cannot be found in the rest of the court's decision, and which is not mentioned in the court's final conclusion. Also, the phrase "In addition, the court attaches some value to" is very vague.

3 The Formalisms

3.1 Abductive Logical Models

We now describe abductive logical models, which were mainly developed for doing diagnosis. Abduction is often described as reasoning from effects to causes, as in 'if fire then smoke; smoke, so fire' (see Figure 1). Taken by itself this scheme is, of course, nothing but the well-known fallacy of affirming the consequent. However, in a setting where alternative abductive explanations are generated and compared, it can still be rational to accept an abductive conclusion, namely, if no better explanation is available. Clearly, such reasoning is defeasible, since additional facts might give rise to new explanations.

Abductive-logical models simulate the abductive inference scheme of Figure 1 with a particular use of classical-logical inference. Basically, given a set T of causal rules and a set F of observed facts, they produce one or more *explanations* H of sets of possible causes ("hypotheses") for these observations in terms of the causal rules. More precisely, an explanation is a set H such that

- $H \cup T \vdash f$ for every $f \in F$; and
- $H \cup T$ is consistent.

The causal rules in T are often assumed to be of the following form:

$$c_1 \land \ldots \land c_n \rightarrow e$$

were $c_1, \ldots, c_n$ are literals, standing for causes that in conjunction produce the effect e, which also is a literal. Causal rules can be chained, since effects can in turn be causes of other effects.

In legal cases the task typically is to find the most likely cause of one or more particular observations (the 'explanandum'). For instance, in our case the task is to find the most likely cause of the car crash, since the one who caused the accident is responsible for the resulting damages. However, usually there will also be additional observations, viz. the evidence; for instance, in our case we have evidence of tire marks, of the position of the handbrake after the accident, etcetera. Alternative explanations should be compared on the extent to which they explain or contradict these additional observations. Accordingly, we define an *abductive causal problem* for present purposes as a tuple $\langle T, C, O, F, A \rangle$ where

- T is a causal theory;
- C is a set of possible causes;
- O is a set of possible observations;
- $F \subseteq O$ is a set of facts to be explained (the explanandum);
- $A \subseteq O$ is a set of additional evidence, disjoint from F.

A *solution* to such a problem is a set $H \subseteq C$ such that H explains F.

Abductive-logical models have been augmented with several other features, but for present purposes this is all we need.

Many metrics have been proposed for comparing alternative solutions. Here are some obvious criteria (which all three order sets in terms of set inclusion):

- the smaller H, the better;
- the larger the set of explained additional evidence, the better;
- the smaller the set of contradicted additional evidence, the better.

It should be noted that we have deviated from most logical models of abduction in that they usually require solutions to explain all additional evidence A as well as the explanandum F, and that they do not allow explanations to contradict the additional evidence. We think that such a definition for solutions is too strong for legal practice and that the additional evidence A should only be used to assess the quality of solutions.

3.2 Logics for Defeasible Argumentation

Argument-based logics formalise nonmonotonic reasoning as the construction and comparison of arguments for and against certain conclusions. The input of an argumentation system is a set of arguments and a relation of strength between arguments, and the output is an assignment of a status to arguments. Typically this status is defined in terms of three classes: the ‘winning’ or *justified* arguments, the ‘losing’ or *overruled* arguments, and the ‘ties’, i.e., the *defensible* arguments, which are involved in an irresolvable conflict. In some systems, the strength relations between arguments are themselves derived within the system.

As for attacks on arguments, a common distinction in the literature is that between *rebutting* and *undercutting* attacks. Rebuttals are arguments with opposing conclusions, while undercutters deny that an argument’s premises support its conclusion. A third kind of attack has also been distinguished (but is often reduced to one of the other kinds), *assumption* attacks, which deny an explicit assumption made in an argument.

Most argument-based systems have so far been applied to ‘rule-’ or ‘logic-based’ reasoning, but their general setup leaves room for defining any notion of an argument, including inductive, abductive and analogical arguments. In reasoning about evidence especially inductive and abductive reasoning is important. In this paper we concentrate on abductive reasoning.

4 Abductive-Logical Reconstruction

We now turn to an abductive-logical reconstruction of the case. We first give its causal structure, obtained from the information provided by all available sources, in Figure 2. The signs associated with the arcs in the figure indicate whether the proposition at the head of an arc supports (+) or contradicts (−) the proposition stated at the tail of the arc. The darkly shaded nodes represent the evidence that was observed to be true, while the only lightly shaded node represents a piece of evidence that was observed to be false. Note that although the figure resembles a Qualitative Probabilistic Network [17] it has no relation to the QPN formalism whatsoever.

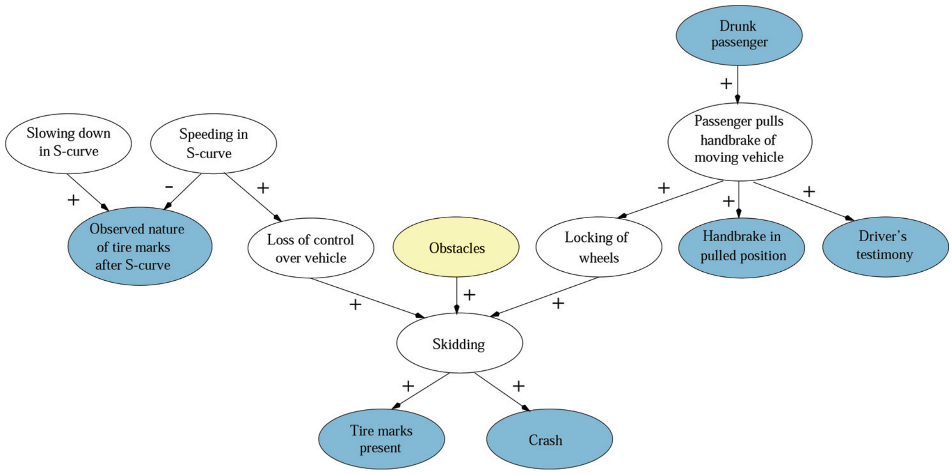

Figure 2: Causal structure for the case.

We now list the causal theory and observations. Since the outcome of the case depends on who caused the accident, the task is to find the best explanation for the observation *accident*. So, our 'explanandum' F contains just *accident*, and the evidence A contains the following facts:

(1) ¬ *obstacles*
(2) *tire marks present*
(3) *observed nature of tire marks*
(4) *handbrake in pulled position after accident*
(5) *driver said "passenger pulled handbrake"*
(6) *passenger was drunk*

For simplicity we have not distinguished between the skidmarks and yaw marks. Note also that the content of the expert witness report is not part of the evidence, since in fact this report states a causal rule, namely, rule r_5 below.

The causal theory T is directly derived from the links in Figure 2.

r_1: *skidding* $\Rightarrow$ *accident*
r_2: *skidding* $\Rightarrow$ *tire marks present*
r_3: *obstacles* $\Rightarrow$ *skidding*
r_4: *loss of control* $\Rightarrow$ *skidding*
r_5: *wheels locked* $\Rightarrow$ *skidding*
r_6: *speeding in curve* $\Rightarrow$ *loss of control*
r_7: *speeding in curve* $\Rightarrow \neg$ *observed nature of tire marks*
r_8: *slowing down in curve* $\Rightarrow$ *observed nature of tire marks*
r_9: *passenger drunk* $\Rightarrow$ *passenger pulls handbrake*
r_{10}: *passenger pulls handbrake* $\Rightarrow$ *wheels locked*
r_{11}: *passenger pulls handbrake* $\Rightarrow$ *handbrake in pulled position after accident*
r_{12}: *passenger pulls handbrake* $\Rightarrow$ *driver said "passenger pulled handbrake"*

Now C, the possible causes, consists of all antecedents of any of these causal rules, while O, the possible observations, includes all consequents of any such rule plus (1) and (6).

Next we list the formal counterparts of the solutions offered by plaintiff (π) and defendant (δ). For plaintiff we choose to combine his main and secondary argument as summarised by the judge.

$H_\pi = \{(7)$ *speeding in curve,* (8) *loss of control*$\}$
H_π additionally explains (2)
H_π contradicts (3)

$H_\delta = \{(9)$ *passenger pulled handbrake*$\}$
H_δ additionally explains (2,4,5)
H_δ contradicts nothing

Using any of the three criteria mentioned at the end of Section 3.1, we see that defendant's solution is clearly better: we have that $H_\pi \not\subset H_\delta$, while H_δ explains more and contradicts less evidence. So along these criteria the court's relative assessment of the two solutions is more than warranted (since plaintiff had the burden of proving that defendant caused the accident, it sufficed for the court to say that plaintiff's solution is not more likely).

This abductive reconstruction of the court's decision seems reasonably close to the actual wording of the decision (subject to the caveats made in Section 2). However, an aspect of the decision that is not captured is the court's use of passenger's observed drunkenness as an extra factor favouring defendant: although (6) could be added to H_δ, this would not improve its quality according to the metrics proposed above.

5 Argument-Based Reconstruction

We next give an argument-based reconstruction of the case. It will be presented semiformally, since for present purposes the style of formalisation is more important than the precise details. The reconstruction follows a 'modus-ponens' approach (very usual in nonmonotonic logic), in which, roughly, arguments are constructed with standard-logical reasoning and 'modus-ponens-like' reasoning with default conditionals. In particular, we exclude the construction of abductive arguments, i.e., arguments based on the scheme of Figure 1 above. This is for the simple reason that the notion of an abductive argument has not yet been defined for argument-based systems. For the rest, we will display arguments as trees of inference steps. The causal and evidential rules ‘warranting’ the various inference steps will be left implicit.

Given the choice for a modus-ponens approach, one question immediately arises: must causal knowledge be represented as $cause \Rightarrow effect$ rules or as $effect \Rightarrow cause$ rules? In terms of Pearl [10], do we want to represent causal knowledge as *causal rules* or as *evidential rules?*

The causal model of Figure 2 suggests that we need both kinds of rules, since we both need to do *explanation*, i.e., derive causes from effects, and *prediction*, i.e. derive effects from causes. For instance, we must be able to explain the evidence *driver’s testimony* and *handbrake in pulled position* with the hypothesis *passenger pulled handbrake*, but then we must be able to predict *wheels locked* from this hypothesis. In our modus-ponens approach this requires the two rules

r: *driver said “passenger pulled handbrake”* $\&$ *handbrake in pulled position* $\Rightarrow_E$ *passenger pulled handbrake*
r': *passenger pulled handbrake* $\Rightarrow_C$ *wheels locked*

The first is an evidential rule and the second a causal rule.

More generally, in a modus-ponens approach causal knowledge should be represented as follows: each time we want to do a prediction, we must write a causal rule, while each time we want to do an explanation, we must write an evidential rule.

However, caution is required here: Pearl [10] shows that if the modus-ponens approach is applied to a mixture of causal and evidential rules, not all modus ponens inference steps may be made. Consider the following case

$$\frac{P_C \quad P \Rightarrow_E Q}{Q}$$

where $P \Rightarrow_E Q$ is an evidential rule and the subscript in P_C indicates that P has been derived from a causal rule. In this case modus ponens (which here is an abduction in disguise!) is invalid, since we have already concluded that P was caused by something else. Add, for instance, to the above two rules r and r' the following evidential rule

r'': *wheels locked* $\Rightarrow_E$ *excessive braking*

If we chain r and r' resulting in a causal prediction of *wheels locked*, then we should not subsequently use *wheels locked* to derive its alternative cause *excessive braking* with r'', since we already know its cause.

Our formalisation (Figures 3 – 7) respects this requirement. For instance, plaintiff’s argument chains the evidential rule $0 \wedge 1 \Rightarrow 7$ with the causal rule $7 \Rightarrow 8$ and the ‘responsibility’ rule $8 \wedge 7 \Rightarrow 14$. Further, defendant’s argument chains the evidential rule $4 \wedge 5 \Rightarrow 9$ with the causal rules $9 \Rightarrow 10$, $10 \Rightarrow 11$ (which actually is the content of the expert report), $11 \Rightarrow 0$ and with the responsibility rule $0 \wedge 9 \Rightarrow 15$. So, none of the arguments chains a causal with an evidential rule.

As for the attack relations, note that plaintiff’s and defendant’s arguments rebut each other, while the court’s two counterarguments J_1 and J_2 undercut and rebut, respectively,

$$\dfrac{\dfrac{\dfrac{(0)\ \textit{accident} \qquad (1)\ \neg \textit{obstacles}}{(7)\ \textit{speeding in curve}}}{(8)\ \textit{loss of control}} \qquad (7)\ \textit{speeding in curve}}{(14)\ \textit{driver caused accident}}$$

Figure 3: Plaintiff's (= passenger's) argument P (including P^{sub})

$$\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{(4)\ \textit{handb in pulled pos} \qquad (5)\ \textit{driver said ``pass pulled''}}{(9)\ \textit{pass pulled handbrake}}}{(10)\ \textit{wheels locked}}}{(11)\ \textit{skidding}}}{(0)\ \textit{accident}} \qquad (9)\ \textit{pass pulled handb}}{(15)\ \textit{passenger caused accident}}$$

Figure 4: Defendant's (= is driver's) counterargument D

$$\dfrac{(3)\ \textit{observed nature of tire marks}}{\{0,1\}\ \textit{don't support}\ 7} \qquad \dfrac{(3)\ \textit{observed nature of tire marks}}{(12)\ \textit{slowing down in curve}}$$

Figure 5: Judge's counterarguments J_1 and J_2

$$\dfrac{(3)\ \textit{observed nature of tire marks}}{J_2\ \textit{not weaker than}\ P^{sub}}$$

Figure 6: Judge's first priority argument J_{p_1}

$$\dfrac{(5) \quad (4) \quad (13)\ \textit{expert report} \quad (2) \quad (3) \quad (6)\ \textit{passenger was drunk}}{D\ \textit{not weaker than}\ P}$$

Figure 7: Judge's second priority argument J_{p_2}

plaintiff's subargument P^{sub}, which concludes (7) from (0) and (1). As for argument assessment, the court's first priority argument prefers J_2 over P^{sub} while its second priority argument says that plaintiff's argument P is not stronger than defendant's counterargument D. It should be obvious that, given these priority arguments, no reasonable argument-based system will regard plaintiff's argument as justified.

This argument-based reconstruction also seems reasonably close to the actual text of the decision. Strong points are that the court's assessment of the evidence can be formally expressed as arguments, and that the contributions of the three parties to the dispute are distinguished as separate arguments, rather than being mixed in one global analysis. On the other hand, the argument-based reconstruction seems rather ad hoc in its treatment of causation. For instance, whether a cause-effect relationship is stated as a causal or an evidential rule depends on how the rule is used in the reasoning process rather than on an analysis of the concepts underlying causal reasoning. Also, the court's assessment of the conflicting arguments can merely be expressed, not be justified, as done by the abductive-logical reconstruction.

6 Discussion

Of course, from a single example no definite conclusions can be drawn. The present results can be no more than clues for further research. With this in mind, the following can be said. Recall that the aim was to compare the two formalisms on their rational well-foundedness and on their naturalness for users of procedural-support systems.

As for rational well-foundedness, we think that the abductive-logical analysis of our case does better than the argument-based formalisation. The former is based on clear and intuitive concepts of causal reasoning. Furthermore, it not only *expresses* the court's decision, but also provides criteria for assessing its rational quality (although the question as to the proper criteria is still far from solved; see e.g. Thagard and Shelley [15]). Finally, the abductive reconstruction is reasonably close to the actual wording of the decision, which compares alternative explanations of the accident.

On the other hand, as for naturalness, the 'deep' causal analysis forced by the abductive-logical model cannot really be found in the court's decision, so that the 'shallow' argument-based reconstruction seems closer to the text of the decision and therefore more natural. (Here, of course, the issue arises whether a procedural-support system should merely offer support for *structuring* the user's reasoning or also for *improving* it.) In sum, both approaches have their strong and weak points, and there is no clear 'winner'.

However, it is easy to imagine hypothetical variants of our case where limitations of the abductive-logical approach become apparent. While in this approach the causal theory and the observations are beyond debate, in legal cases anything can be disputed. Consider a hypothetical variant of the case in which the adversaries disagree about whether pulling the hand brake while driving can cause skidding. In fact, this is a dispute about the 'backing' or justification of a causal rule, where the expert witness testimony can be used to argue for its backing, but where counterarguments (such as questioning the witness' expertise) are allowed. With abductive-logical models, a choice between conflicting views on causation has to be made when designing the causal theory. An argument-based system, by contrast, can easily deal with conflicting arguments on causation. On the other hand, as yet no argument-based account of abductive reasoning and its relation with other kinds of reasoning is available.

Concluding, this article has provided some preliminary evidence that abductive-logical models have the potential to be useful in legal procedural-support systems. However, to realise this potential, more theoretical research is needed on embedding abductive-logical models in dialectical models of argumentation and dispute. Also, empirical research is needed on whether the various formalisms and concepts are indeed close to the thinking of the potential users of procedural-support systems. For instance, do lawyers really think in terms of causal structures? Are they familiar with the distinctions causal vs. evidential rules and prediction vs. explanation? And do lawyers naturally think in terms of argument, attack and defeat, or perhaps in terms of other concepts? Finally, the criteria on which the two formalisms where compared in this paper, rational well-foundedness and naturalness, only provide necessary but not sufficient conditions for usefulness in procedural-support systems. Such usefulness must still be investigated in future research.

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